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LOW-CARBON STEEL CASTINGS IN SHELL MOLDS

by

R. G. Powell* and H. F. Taylor**

Castings of low-carbon steel can be successfully produced in "chill type" shell molds. This has been determined in the course of a recent research project sponsored at Massachusetts Institute of Technology by the Department of the Army through Watertown Arsenal.

The authors found, in a previous research project for the Steel Founders' Society of America,[1] that surface defects of low-carbon steel castings made in regular sand-resin shell molds were completely eliminated when commercial forsterite, or olivine, was used instead of silica sand for making the molds. This is illustrated by the castings shown in Figures 1 and 2.

The theory was advanced, at the time of this finding, that the chilling ability of forsterite probably accounted for its performance. A confused situation existed, however, because forsterite definitely gave better results than zircon, even though zircon had been rated a better chill than forsterite in a previous study on chilling ability of various molding refractories.[2] Since this chill rating was made from data on the cooling rate of relatively large steel spheres with a thermocouple in their center, and a difference exists between a surface chill and a section chill, the authors felt that forsterite possibly was a better surface chill than zircon.

Data on the thermal conductivity of olivine were kindly furnished by Dr. Aslak Kvalheim of the Government Raw Materials Laboratory in Trondheim, Norway, in which country olivine is extensively used in general foundry practice. These data, which are reproduced in Figure 3, indicate that olivine has three to four times the conductivity of silica sand at low temperatures. Its conductivity, however, decreases rapidly with increasing temperature while that of silica increases. This explains why forsterite would be a good surface chill but not a good section chill on steel castings. In comparison, the thermal conductivity of zircon is about twice that of silica at low temperature but it decreases much less rapidly than that of forsterite with increasing temperature.

Dr. Jose Navarro found, in other work at M.I.T., sponsored by Watertown Arsenal, that calcium carbonate powder was a beneficial additive to shell molds for producing low-carbon steel castings.[3,4] In the present research the beneficial action of calcium carbonate was related to its endothermic decomposition and the further endothermic reaction of CO_2 with carbon from the resin binder. Chill type shell molds were made by blending large amounts of granulated limestone with silica sand to produce the same results as had been found with forsterite.

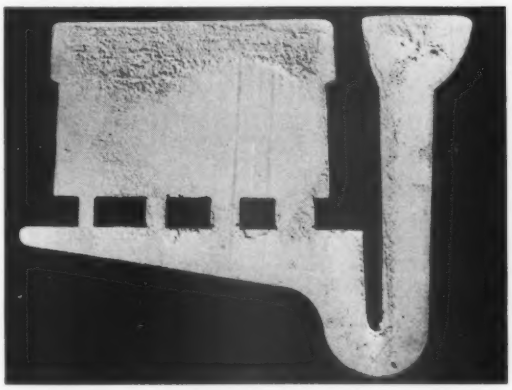

Figure 1—Back of experimental step casting. Made of low-carbon steel in a silica sand-resin shell mold. Poured at 2900°F. Weight about 13 pounds.

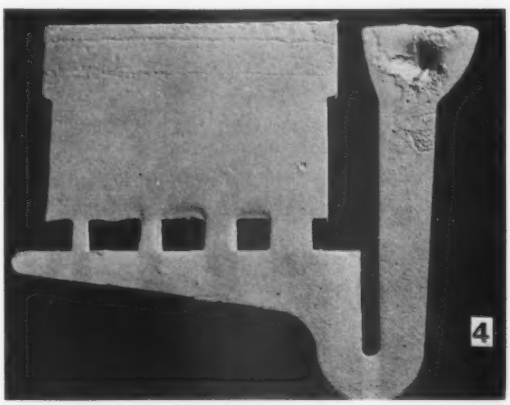

Figure 2—Experimental castings made of low-carbon steel in a forsterite shell mold. Poured at 2900°F.

Taking the molecular weight of calcium carbonate as 100, the following two reactions indicate that calcium carbonate in shell molds would absorb roughly 800 calories per gram. In comparison, the heat of solidification of steel is of the order of 70 calories per gram. The implication is clear that an appreciable chilling effect can be obtained by adding enough calcium carbonate.

(1) $CaCO_3 \rightarrow CaO + CO_2 \quad \Delta H_0 = -41{,}800$ cal.

(2) $CO_2 + C \rightarrow 2\,CO \quad \Delta H_0 = -41{,}600$ cal.

* Research Staff Member and ** Professor of Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass.

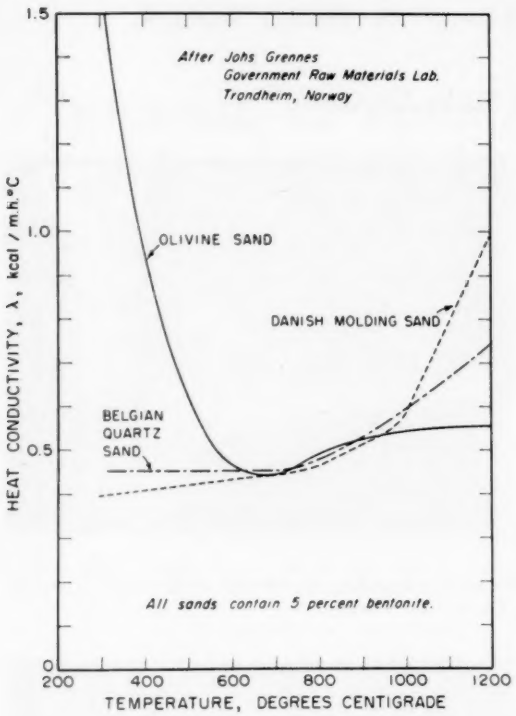

Figure 3—Conductivity of olivine compared with that of silica sand.

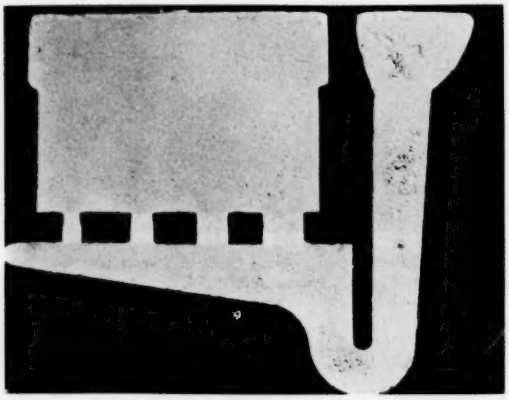

Figure 4—Experimental casting made of low-carbon steel in a shell mold of silica sand blended with 10 percent granulated limestone. Poured at 2950°F.

A practical limitation exists, however, when using powdered carbonate because low mold strength is obtained if more than 3 percent powder is employed. The use of granular material solved this problem and about 10 percent limestone was blended with silica sand to produce the casting shown in Figure 4. In addition to curing the bad surface condition of low-carbon steel castings made in shell molds, granulated limestone also prevents swelling of castings which often occurs with larger sizes; and it considerably improves resistance of molds to thermal shock.

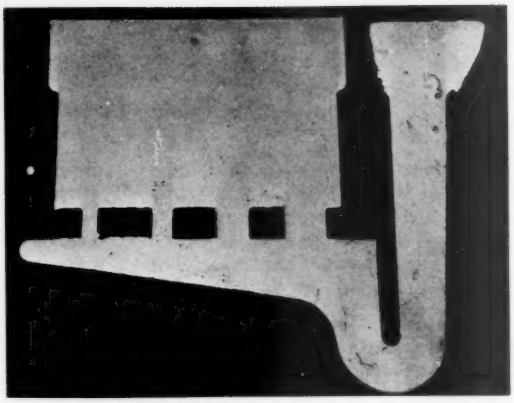

Figure 5—Experimental casting made of low-carbon steel in a composite forsterite shell mold having a thin facing of silica sand. Poured at 2875°F.

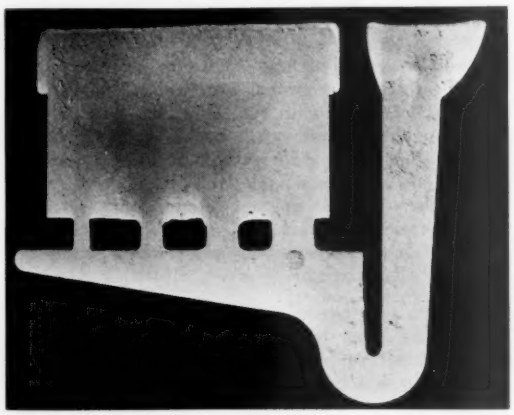

Figure 6—Experimental casting made of low-carbon steel in a composite shell mold having a thin facing of fine silica sand and a backing of coarse silica sand blended with 28 percent granulated limestone. Poured at 2875°F.

Poor sharpness of detail on castings made in forsterite molds and surface pitting on castings produced in silica sand-limestone molds are other difficulties for which a solution has been found. This solution is to employ composite shell molds having a thin facing of silica sand, which are made by a process of double investment previously described by the authors.[5] Castings made in such molds are shown in Figures 5 and 6. The facing material should be of fine sand and about a sixteenth inch in thickness. The back up layer can be a mixture of limestone and coarse sand or pure limestone.

SURFACE DEFECTS OF SHELL MOLDED CASTINGS

Shell molding has proved to be an important method of preparing molds for making castings in nearly all engineering metals and alloys. However, the process still presents a number of problems for the casting of steel. One of these is a surface roughness, commonly known as pitting effect, which frequently appears on carbon and low alloy shell molded steel castings. An article by W. J. Jackson of the British Steel Castings Research Association, recently published in the Association's Journal, reported some interesting observations based on the metallographic examination of shell molded castings exhibiting this defect. The article also analyzed the problem of carbon pick-up through metallographic examination.

A number of 0.40 and 0.50 percent carbon shell molded steel castings were produced with the use of ordinary oil-sand cores, thus making possible, in a single casting, a comparison of the microstructures at a shell mold and core sand surface. Pitting defects were obtained on the shell molded surfaces of the completed castings, while the core sand surfaces were free from any defect. An ordinary commercial powdered resin was used in making the shell molds.

Metallographic Examination

Sections in the as-cast condition and containing the surface defect were polished and examined unetched, and etched in nital, picral and Oberhoffer's reagent.* The latter is a useful etchant for revealing the mode of solidification of a steel for it does not attack the phosphorus-rich areas which result from dendritic segregation during solidification. (Copper is deposited first on areas lowest in phosphorus.)

Cupric chloride	1 g
Stannous chloride	0.5 g
Ferric chloride	30 g
Hydrochloric acid (conc.)	30 ml
Ethyl alcohol	500 ml
Water	500 ml

(Methyl alcohol may be used in place of ethyl alcohol.)

Etching in nital revealed that in each casting below the surface, which had solidified adjacent to the shell mold, there existed a decarburized band, behind which was a carburized band which merged into the normal as-cast structure (see Figure 1). The depth of the composite decarburized/carburized zone (which appeared as one band after etching in Oberhoffer's reagent) varied from 0.35 mm to 0.9 mm, but was mostly about 0.45 mm thick. The dendritic structure in this band was very coarse, suggesting that very slow solidification had taken place. Further evidence was provided by the larger and more pronounced sulphides which were observed in the band, typical examples of which may be seen in Figure 1.

Also, after etching in Oberhoffer's reagent, between the well defined decarburized/carburized

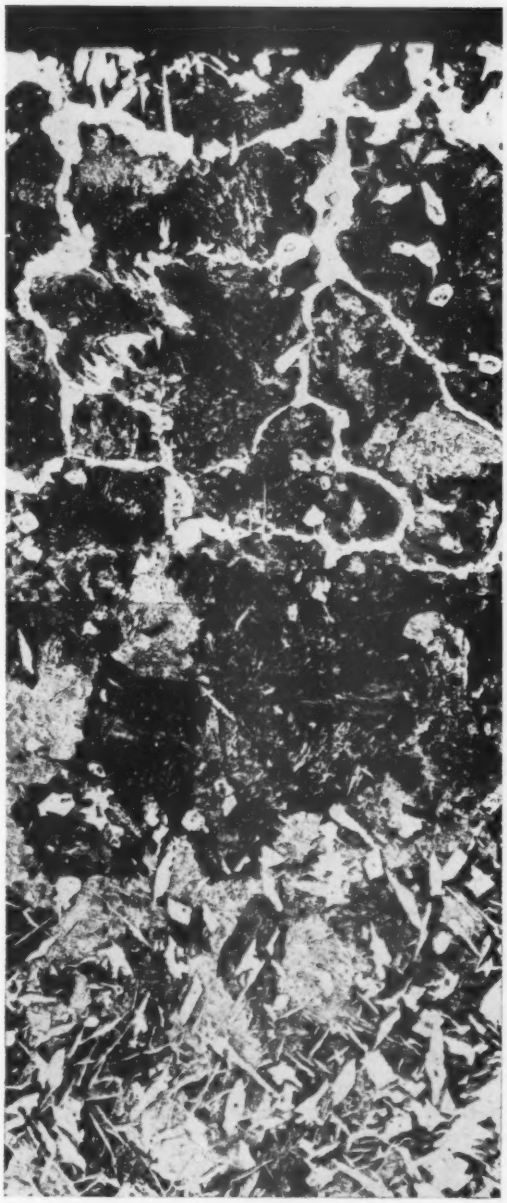

Figure 1—Microstructure of a 0.40 percent carbon steel at shell mold surface, showing decarburized-carburized zone merging into the as-cast structure. Etched in 2 percent nital, 110X.

* Oberhoffer's reagent (see "Metallographer's Handbook of Etching", Berglund. Pitman, 1931).

band and the general dendritic structure, there appeared an unetched (white) band, suggesting that solidification here was too rapid for phosphorus segregation to occur. On the core sand face of the casting, the unetched (white) band similarly represented chilled crystals.

Proposed Mechanism of Formation of Defect

The following succession of events is suggested to explain the observed variation in microstructure (Figure 1) and the surface depressions which occur on the shell mold surface of the casting.

On filling the mold with molten steel:

1. A chilled crystal zone approaching 1.5 mm thickness is first formed.
2. Decomposition of the resin occurs with evolution of gas and heat, the latter being sufficient to cause partial remelting at the surface.

   The gas pressure is sufficient to force depressions into this liquid-solid zone, which give rise to the pitting effect.
3. Before the surface layer again solidifies, carbon is rapidly picked up from the burnt resin and diffuses uniformly throughout the liquid-solid zone.
4. The casting as a whole solidifies and becomes (inhomogeneous) austenite.
5. As a result of the surface oxidation which takes place while the casting is cooling through the austenite phase field, a concentration gradient of carbon is formed by the outward diffusion of carbon from the carburized zone.
6. When the average Ar_3 temperature is reached, precipitation of ferrite commences in the areas of lowest carbon (i.e., where the Ar_3 temperature is highest). Thus more ferrite appears at the surface of the casting, and less in the carburized zone.

Discussion

That the combustion of the resin used in sand molds is highly exothermic is well illustrated by the fact that a method of reclaiming sand from spent molds is to ignite the molds in a vertical incinerator. The heat evolved is sufficient to cause complete combustion without using any other fuel, and the reclaimed sand trickles out at the bottom ready for further use.

It is probable that, at the time when the outer zone is in the liquid-solid condition, the evolution of gas is so rapid that it cannot all permeate through the mold. The build-up of gas is large enough not only to force depressions into the liquid-solid zone, but also to distort the remaining solid chilled crystal zone. Furthermore, in other castings examined, gas was trapped between the liquid-solid and chilled crystal zones as evidenced by a series of gas cavities coinciding with the demarcation line between the two zones.

The proposed mechanism would also account for the generally observed pronounced occurrence of the surface defects on the top faces of heavier shell molded castings. At the bottom and sides of these castings the ferrostatic pressure would tend to oppose the generated gas pressure to a greater degree than at the top surface.

A REVIEW OF THE VACUUM TREATMENT OF MOLTEN METAL

By Francis H. Hohn*

The arrival of the atomic, jet, and missile era has created a somewhat sudden demand for high strength metals and castings, especially for service at elevated temperatures.

The foundryman is, therefore, confronted with the dual necessity of wringing the last bit of strength out of conventional metals and alloys, and of developing entire new lines of super metals and alloys.

One of the tools which is helping to meet this challenge is the application of vacuum melting, pouring, and casting techniques.

The purpose of this paper is to briefly describe some of these techniques with regard to terminology, equipment and procedures. A do-it-yourself vacuum melting furnace will also be described. It is hoped that the information may be of some assistance in determining whether vacuum treating techniques might have some value in a particular shop or operation.

* Metallurgist, Scullin Steel Company, A Division of Universal Marion Corporation, St. Louis, Missouri.

The negative aspect or limitations of conventional air melting and casting techniques will be considered first to point out the advantages of vacuum treatment.

Many of the ills of steel castings in the form of impaired structural or mechanical properties can be attributed to the contamination of the metal during the period that it is molten by such elements as nitrogen, hydrogen, oxygen, sulfur, phosphorus, tin, antimony, etc., either in elemental or combined form. This contamination can occur from the atmosphere, fuel, furnace refractories, mold materials, moisture, poor scrap, etc.

The most obvious effect of dissolved hydrogen and nitrogen in steel is the formation of the familiar pinholes and blowholes in the solidified casting. Oxygen, by reacting with carbon to form carbon monoxide, or with hydrogen to form steam, can also give rise to a porous condition during solidification. Dissolved hydrogen can also give rise to temporarily impaired ductility properties. There is also some evi-

dence that dissolved nitrogen has a detrimental effect on rupture strengths.

Compounds formed by the contaminants in the molten steel such as oxides, hydrides, nitrides, sulfides, etc., usually result in impaired ductility and strength. Careful selection of raw materials and melting and pouring practices, of course, can hold contamination of the melt to a minimum but cannot eliminate it entirely.

Normally, the dissolved oxygen is tied up in the form of a stable oxide by adding a deoxidizing element such as aluminum. This results in an oxide inclusion to interrupt the continuity of the metal structure, and adds still another contaminant in the form of residual aluminum. If insufficient aluminum is added, the shape of the oxide inclusion is such that ductility is impaired. If too much aluminum is added in the presence of nitrogen, the steel becomes embrittled. Ninety percent of the aluminum is lost to air oxidation in attempting to get it into solution, adding additional dross like aluminum oxide inclusions to the melt, and increasing the probability of forming ceroxide defects in the castings. All of this explanation is by way of showing how in attempting to deal with one contaminant, the melt must be contaminated still further.

Air melting imposes an additional disadvantage when such alloying agents as titanium, boron, cerium, etc., are to be added to the melt. Air oxidation makes it necessary to add excessive amounts of these materials to effect the desired recovery. In the case of such reactive metals as titanium, zirconium, uranium, etc., melting under vacuum or inert atmospheres is necessary.

It might be well here to point out that the term vacuum is a relative term and is defined by Webster as a degree of rarefaction well below atmospheric. In vacuum melting, the entire melting operation is carried out in an enclosed furnace which is exhausted by suitable pumps. A vacuum of 1 micron or less is not at all unusual (1 micron is equivalent to 0.001 mm—normal atmospheric pressure is approximately 760 mm.)

Vacuum melting eliminates the contamination difficulties inherent in air melting, resulting in cleaner, more uniform, and stronger metals in the following ways:

1) Exclusion of air from vacuum melts eliminates the principal source of the gases responsible for blowholes and pinhole porosity.

2) Dissolved gases entering the melt from the charge boil off and are exhausted by the pumping system.

3) Sulfides can be removed by adding metallic oxides to the melt.

4) Metallic oxides which do not dissociate at the reduced pressures used in vacuum melting may be removed by deoxidizing with dry hydrogen.

5) Hydrides and nitrides decompose and are exhausted from the melt.

6) Such residual contaminants as magnesium, lead, zinc, tin, antimony, etc., are removed through volatilization.

7) A virtual 100 percent recovery of such alloying elements as titanium, aluminum, and boron is effected with exclusion of air.

Most metals show tremendous improvements in various strength properties, with the removal of nearly all dissolved gases and inclusions during vacuum melting.

There are other forms of the vacuum treatment of metals besides vacuum melting which will be discussed later, and which usually generate somewhat lesser improvements in strength properties, depending upon the amount of contaminants which are removed.

The following are typical improvements effected in various metals by vacuum melting:

1) 4340 steel shows a 25 percent increase in fatigue strength.

2) The impact strengths of 403 and 422 stainless steels are increased 300 to 600 percent over their air melted counterparts.

3) The Cr-Ni-Co-Mo-Ti alloys show a 10.5 percent increase in fatigue strength and a 94 percent increase in tensile ductility.

4) Copper exhibits a conductivity close to 100 percent of the calculated theoretical value.

5) The 52100 bearing steels free of inclusions are characterized by a four-fold increase in service life.

6) Vacuum melted iron shows a 60 - 70 percent greater resistance to rupture. Elongation is increased as much as 400 percent.

7) Freed of surface imperfections, some alloy steels show increased corrosion resistance (Hasteloy).

8) Wire steels are tremendously improved.

Some of the present uses for vacuum melted metals are: watch springs, X-ray and vacuum tube parts, parts for the atomic, jet engine and missile programs, ball bearings, high quality tool steels, valve springs, magnetic steels, etc.

The advantages of melting metals in vacuum have been known for well over 50 years; but early interest was more or less of an academic nature and limited mostly to determination of such things as melting points, freezing points and properties of pure metals.

W. C. Arsem, in a report to the Electro-chemical Society in 1906, pointed out that vacuum melting would purify metals by volatilization of impurities; and also that, through the avoidance of air oxidation, more exact compositions could be retained. Several

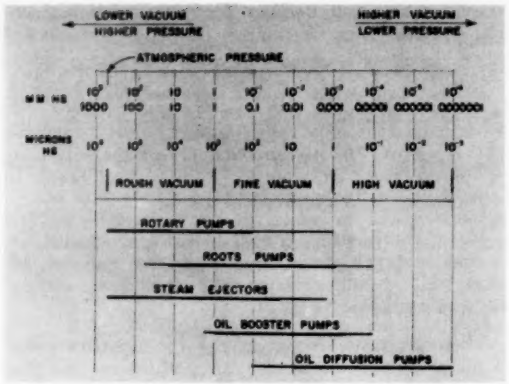

Figure 1—Various types of vacuum pumping equipment and their operating pressure ranges.

small furnaces were in existence by 1920 for vacuum melting up to five (5) pound charges. A German firm was producing commercial quantities of vacuum melted nickel-chromium alloys about this same time; but, compared with today's standards, the vacuums were very crude indeed. Large-scale vacuum melting and vacuum treating operations had to wait for the development of more efficient pumping equipment such as multistage diffusion pumps and large capacity booster pumps. This development occurred during and after World War II.

Figure 1 illustrates the range of various types of pumping equipment now in use and gives some of the details of vacuum terminology and units. Note that the mechanical rotary pumps and steam ejector pumps are the only ones which will operate with atmospheric fore pressure. Mechanical pumps, however, cannot generate the high vacuums obtainable with booster and diffusion pumps; so that ordinarily, most pumping installations consist of two or more of these various type pumps in series.

Also, note that high vacuum is generally accepted as absolute pressure in the region below 0.001 mm or 1 micron. Fine vacuums are in the range of 0.001 mm to 1 mm or 1 to 1000 microns. Rough vacuums are of the order of 1 mm to 760 mm of mercury.

A single stage rotary pump which can be used alone or in combination with a booster pump is the oldest and most common type pump and is essentially nothing more than a compressor operating against atmospheric pressure. A mechanical booster pump has high pumping speeds and can generate rather high vacuums. It usually consists of a positive lobe type rotary pump backed up by a cam and piston pump.

The steam ejector pump, which is not widely used at this time, makes use of the nozzle or venturi principle for creating a vacuum. Ordinarily, six or more of these units are used in series. Oil vapor may be used in place of steam, in which case the pump is termed an oil ejector pump.

The oil diffusion pump, which in combination with a mechanical type pump will give the best combination of high pumping speed and low ultimate pressure, was first designed by Burch in 1929. This pump generally consists of three parts, none of which are moving: (1) The bottom cylindrical boiler section provided with some heating means to vaporize the oil, (2) the inner jet manifold, (3) the outer water-cooled jacket or condenser. In operation, air molecules from the furnace are picked up and deflected in a downward direction by jets of oil vapor to a point where they can be pumped out by the mechanical pump. The oil vapors striking the cool walls of the jacket condense and run back into the boiler to be vaporized again.

How these pumps would fit into a high vacuum system is shown schematically in Figure 2. The roughing valve would be opened to initiate the pumping cycle, and the mechanical pump started and allowed to run until the pressure is down to such a point that the diffusion pump could be used. Then the high vacuum and foreline valves are opened, the roughing valve closed, and pumping continued until the desired vacuum is attained. The valves used in a high vacuum system are of special design to prevent leaks and outgassing in all positions. Special gauges called McLeod gauges are required to measure high vacuums.

Vacuum melting furnaces may generally be classified as follows:

1) Resistance
2) Induction
3) Arc
   a) Consumable electrode
   b) Non-consumable electrode
4) Levitation
5) Zone melting

The resistance furnace, utilizing high-temperature heating elements or other resistance heating, is rarely used in vacuum melting except possibly for small laboratory models because of temperature limitations; although one of the very first vacuum melting furnaces was of this type, and was designed by W. S. Simpson, an Englishman, in 1913.

The induction furnace, on the other hand, is widely used for vacuum melting with upwards of 65 sizable installations in this country. The heat in induction furnaces is developed by eddy currents induced by a high frequency induction coil surrounding the crucible and charge. Crucibles may normally be constructed of graphite, magnesia, zirconia, or other refractory materials. The molten metal can be lip poured from the crucible by tilting either the crucible or furnace or bottom poured through a tapping plug arrangement. There are many types of induction and arc melting furnaces available in both production and laboratory sizes.

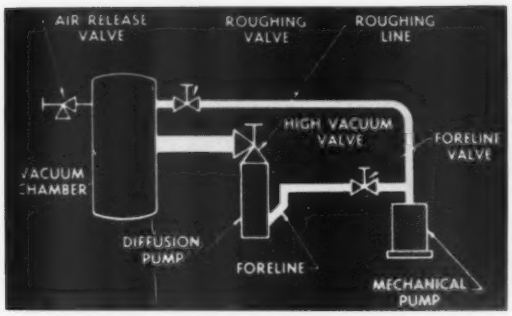

Figure 2—Schematic drawing of a vacuum installation using the various types of pumps.

One of the first commercial vacuum melt furnaces was installed in the German firm of Heraeus Vacuum Schmelze about 1923. It was of the high frequency induction type with a capacity of up to 8000 pounds. The induction coil, crucible, and mold were all housed within the vacuum chamber. The crucible was equipped with a stopper rod assembly so that the melt could be tapped through the bottom of the crucible directly into the mold. Furnace operating pressures were in the range of 5 to 10 mm.

One of the first induction vacuum furnaces in this country was designed by Reeve of Western Electric and employed the tilting furnace principle. In one of the modern induction melting furnaces the charge is contained in a can which is lowered into the refractory crucible for melting. Molds are elevated by means of a hydraulic ram from a detachable, evacuated mold chamber through a bottom furnace port, and into a position to be filled by the tilted crucible. Interlocks are provided so that the crucible may be charged, alloying elements added, and ingots removed without breaking the vacuum in the main chamber.

Vacuum induction melting is also being currently used for investment castings. The nickel and iron base investment castings made at pressures of less than 10 microns show superior surface and strength properties. Also, closer control of chemical analysis is possible. The charge for this type furnace could consist of portions of larger air melted or vacuum melted master alloys.

Die casting of vacuum melted metals and alloys is also beginning to be used, because it offers such obvious advantages, such as:

1) Entrapment of air is avoided
2) Lower injection pressures may be used
3) The design of dies can be simplified, since elaborate venting and the use of overflows are no longer needed to prevent air entrapment.

While the induction vacuum melting process is widely used, it has several serious limitations:

1) Small batches - It has been estimated that 5000 pounds is probably the practical size limit for this type furnace.
2) Low melting rates
3) Contamination of the melt by the crucible refractory. Thus, alumina will dissociate at high temperatures to either react with the metal being melted or liberating a gas.

The next most widely used vacuum furnace is the arc furnace of which there are some 30 or more installations in the U. S. Most of these furnaces are used for melting such reactive metals as titanium, zirconium, molybdenum, etc. There are 4 such shops melting steel. The heat for melting is generated by a high amperage, low voltage DC arc between an electrode and the melt. Electrodes are of two types, nonconsumable and consumable.

Nonconsumable electrodes are usually of carbon, graphite or tungsten tipped and water cooled. The charge, consisting of either a preloaded charge of pure metals and scrap or a partial charge with continuous additions, is tapped into ingot or casting molds.

The metal to be melted, in the consumable electrode process, is machined or shaped into electrodes which are melted down in the process. This method seems to have the most promise for mass production vacuum melting of large ingots on a semi-continuous to continuous basis. The largest ingot made to date is 40 inches in diameter and weighs 29,000 pounds.

The ingot mold is ordinarily of water cooled copper which permits solidification without mold contact, and which can be continuously retracted as metal consecutively melts and solidifies. This consecutive melting and solidification also tends to eliminate inclusions by progressively floating them along the length of the ingot. Because of the quick metal freezing of this process, segregation problems in billets and ingots are avoided.

There are several deficiencies of the consumable electrode process. These are: (1) it requires a high quality electrode; (2) the metal is not molten long enough for complete degasification; and (3) the use of a water cooled mold presents an explosion hazard in the event water finds its way into the melt.

A water cooled crucible is usually employed in the nonconsumable arc melting process, and the material melts in a pool within a frozen crust or skull. At the appropriate time the metal is tapped, usually through the bottom of the crucible.

Limitations of the process are: (1) it is difficult to control; (2) heat sizes are limited by the current carrying capacity of the electrode; (3) because the electrical stirring of the induction melt process is absent, it is difficult to avoid alloy segregation; (4) the melt is contaminated by the electrode; and (5) the explosion hazard.

This might be an appropriate point to mention that many vacuum melting furnaces may be equipped to operate under inert atmospheres instead of under vacuum. The gas used is generally argon, helium or a combination of both. The establishment of the inert atmospheres usually involves several vacuum pump-downs and flushing with gas until, finally, a slightly positive pressure is established. Advantages of inert atmosphere melting are as follows:

1) Existing air melting furnaces can usually be altered for inert atmosphere melting without a large capital expenditure.

2) Relatively inexpensive rough vacuum pumps can be used.

3) Leaks are less of a problem, so that regular good quality valves can be used instead of vacuum tight valves.

Deficiencies of inert atmosphere melting are as follows:

1) Argon is rather costly and is continually consumed by the process.

2) Some alloys lose their vacuum properties when remelted under inert atmosphere.

3) The process is difficult to control, since the condition of the argon blanket is not too easy to determine without rather expensive analytical equipment, such as the mass spectrometer.

Besides the induction melting and arc melting processes just discussed, there are two other processes which are now beginning to emerge from the laboratory stage and bear mentioning. The first of the two is the levitation process in which the metal is melted while suspended in vacuum or inert atmosphere, thus avoiding both electrode and crucible contamination.

The metal to be melted in this system, usually in the form of pressed powder, is placed inside of a copper coil carrying a high frequency electric current where it remains suspended by eddy currents. Heating is by induction, and is very rapid. A vigorous stirring action of the molten mass, brought about by the induced fields and thermal gradients, causes the melt to assume the shape of a top. Alloys may be added while the melt is levitated. The cast is made by current adjustment allowing the melt to drop out of the field. An alternator supplying 10,000 cycle current of 1200 amperes serves as the power source.

The second of these lesser known processes is termed zone melting and has been mainly used in the purification of germanium for transistors. The metal, in the form of a rod, is pulled slowly through a series of inductor coils; so that impurities migrate from the molten portion until eventually they are all contained at one end of the bar from which they may be cropped.

Thus far, the processes of melting under vacuum or inert atmosphere have been discussed; but, simultaneous with this development has come a whole series of other vacuum treating techniques which are applied to conventionally air-melted metals. These other vacuum treating techniques are ladle degassing, stream droplet degassing, and vacuum casting and, for the most part, have had their origin in Germany and Russia.

During the early 1930's there was much interest and activity in vacuum melting and vacuum treating techniques in various parts of Europe. In 1940, Samarin and Novik, two Russian investigators, suggested a method of placing molten steel in a vacuum chamber to remove dissolved gases. (As early as 1935, it was known that high hydrogen contents were responsible for flaking of forgings). Such a process is known as vacuum degasification.

The process is rather simple and not too expensive, involving the placement of the ladle filled with steel and slag into a vacuum chamber and gradually lowering the pressure to between 2 and 30 mm of mercury. The steel begins to boil when the pressure is lowered, and bubbles of burning gases break through the slag to be evacuated by the vacuum system. Care must be taken not to have the ladle too full, or to reduce the vacuum too fast, since there is danger of boiling over. Air is admitted to the vacuum chamber when the evolution of gas has ceased, and the heat poured in the usual manner.

Oxygen contents were reduced 4 to 10 times by this process in Russia for Bessemer steel; and nitrogen contents were reduced 30 to 50 percent with a resultant improvement in mechanical properties, especially low temperature impact values. There are at least 8 Russian steel plants with vacuum degassing installations for 25 ton heats. The Bochumer Verein Co. in Western Germany began its initial studies on vacuum degassing in 1950 and are presently treating 150 ton heats.

Ladle degassing in the U. S. has pretty well been limited to non-ferrous materials, such as copper, aluminum, bronze, etc. In all cases, most of the dissolved gases were eliminated and mechanical properties improved. Disadvantages of the ladle degassing process are: (1) the metal must be super-heated to compensate for the 100 degrees or more temperature drop during degassing; (2) gas removal is incomplete since the ferrostatic pressure limits effectiveness to surface layers.

Stream droplet degassing is accomplished by tapping an air melted heat into a transfer ladle which is used to fill a pony ladle located on top of the vacuum chamber. The teeming hole is sealed with a sheet of aluminum which, at the proper time, is punctured by the flow of molten steel from the pony ladle. The almost instantaneous drop in pressure causes the metal stream to virtually explode into a fine spray permitting very efficient degasification. Degasification rates are up to ten tons per minute. After the ladle within

the chamber has been filled, pressures are equalized and the ladle is removed for conventional air pouring.

Because some temperature loss is involved in the process, the three ladles involved and the vacuum chamber must be efficiently insulated. The deficiency of this process is that the air pouring following the degasification permits further pickup of contaminating gases.

There are now about five large scale degasification installations in the U. S. conditioning steel for use in large forgings, mostly for rotating equipment, such as turbine and generator shafts.

Three years ago, after viewing the rapidly growing developments in the field of vacuum melting and vacuum treating, Scullin Steel Company decided to initiate a research project employing some of these techniques. The principal idea was to determine whether vacuum metallurgy had any application with regard to product improvement and diversification. It was decided that the arc melting method would provide the desired flexibility; and space and budget limitations determined that the equipment would have to be built rather than purchased as a standard unit.

The first problem encountered was a most formidable one, namely, a site for the installation. After much deliberation, it was found that the only available space was an unused women's locker room in the laboratory building. The size of the room is 8 x 13 feet, and it was made available with the understanding that all of the bathroom fixtures remain in place and intact; and so the unit was designed and constructed around and in the bathroom fixtures.

The final furnace design was not too dissimilar from other vacuum arc furnaces in use at the time, except that an unusual amount of flexibility was built into it; laboratory melts of a few ounces could be made, or pilot melts of up to 13 pounds.

Figure 3 shows the completed furnace which essentially consists of four parts:

1) The lid-electrode assembly
2) The melting chamber
3) The pouring chamber
4) The mold elevating assembly.

Air tight seals between the four sections are effected with neoprene "O" rings. The largest section is the pouring chamber, 26-inch I.D., and 18 inches high, made from ½-inch steel plate. It is provided with a 6-inch flanged power port, and 8-inch flanged access port, and a small view port to observe the tap stream.

The pouring chamber is supported by a ½ x 36 x 36-inch plate to which it is welded. An opening in the center of the plate, through a suitable seal and bushing arrangement, accepts the shaft of the mold

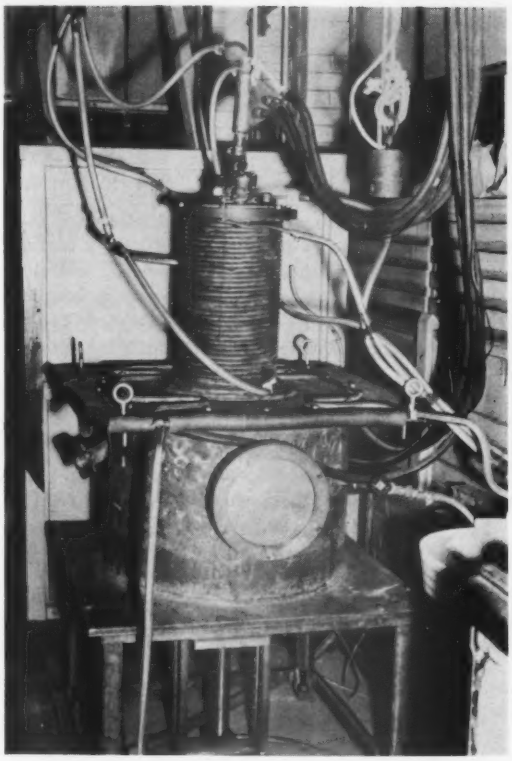

Figure 3—Vacuum arc melting furnace constructed by the author's company.

elevating platform which is raised or lowered by hydraulic jacks, or which may be spun by a suitable motor linkage for centrifugal casting.

The melting chamber base, a ½-inch water cooled steel plate, bolts to the flanged top of the pouring chamber, a large tailor made "O" ring making the seal. Cathode connections from the power source are made to this plate. The melting chamber, 9-inch I.D. by 20 inches high, is formed of ¼-inch copper plate and is wrapped with ½-inch copper tubing for water cooling. Steel flanges are brazed to both ends of the water cooled copper cylinder.

The hearth of the melting chamber for a large heat consists of a round 1-inch graphite plate with a center tap hole and is supported from the base plate. The tap hole is covered with a sheet of metal foil. An insert crucible of copper segments is used for small laboratory heats of 2 pounds or less. The copper support plates contact the water cooled copper cylinder to provide the necessary cooling.

The lid of ½-inch steel is provided with two peep sites to view the arc and, through a center opening suitably insulated, receives the electrode assembly which may be raised, lowered, and rotated if desired

—a neoprene tube makes the electrode seal. The anode connections are made on the end of the electrode.

Two stainless steel radiation shields are suspended from the bottom of the lid. The electrode consists of a 1-inch heavy walled brass tube provided with ½-inch inner copper tube for water cooling. A tungsten tip, 1-inch I.D., 3 inches long, is brazed within the brass tube, and is given additional support with a brass sleeve. The water outlet tube is also of ½-inch copper tubing.

The vacuum pump is in series with a surge tank. The purpose of the surge tank is to permit instantaneous evacuation of the furnace at pouring, whenever an inert atmosphere is used. A solenoid opening the surge tank to the furnace exhaust line is energized by a trip circuit activated by the falling stream of molten metal.

A typical operational sequence for a vacuum melt under inert atmosphere might be as follows:

1) The mold is inserted through the access port and placed in position by adjusting the height of the mold support platform.
2) The charge consisting of scrap, base metal, and alloy is distributed on the hearth as uniformly as possible.
3) The lid is bolted down, and the furnace alternately pumped down to about 1 mm of mercury and flushed with inert gas (8 parts helium and 1 part argon) for 3 cycles.
4) Motor generator sets are started and balanced.
5) The power switch and breaker are closed.
6) The electrode is lowered to strike the arc, after which it is pulled back to establish a suitable arc and moved in a rotary fashion for melting and consolidating the charge.
7) When the heat has been completely melted, except for the skull on the bottom and sides, the electrode is centered over the tap hole, thus melting the metal foil and effecting the cast. The electrode is then retracted to break the arc.
8) The mold is then allowed to cool in the inert atmosphere before removal.

Although there are disadvantages to the arc melting process, as previously mentioned, in the form of control and contamination difficulties, this furnace has been an ideal research tool with very few operating problems.

The author hopes that this paper has provided some food for thought, as to whether this new, old tool of vacuum melting and treating might have some application in steel foundries. It certainly imparts amazing properties to some metals, and a challenge.

It is probably not a good idea to go overboard on this new, old idea of vacuum melting without some careful study. Many metals and alloys prepared by good air melting practices show little, if any, improvement when vacuum melted. Vacuum melting is not the panacea all foundrymen have been looking for, but merely an additional metallurgical tool for improving some old products and developing new products and markets. However, it is of no advantage to go to a lot of trouble preparing gas-free, inclusion-free metal only to pour it into a green sand mold, or even any kind of a sand mold for that matter. To keep pace with this rapidly expanding field of vacuum melting and treating, foundrymen must develop new and better molding materials.

WATER-SOLUBLE CELLULOSE ETHERS AS BINDERS FOR FOUNDRY PURPOSES

By Rolf Moren*

Water-soluble cellulose ethers are widely used in different branches of industry as binders, thickeners, emulsifiers and stabilizers. Cellulose ethers have in recent years also found a significant new market within the foundry field. The products are applied as core and molding sand binders in conjunction with synthetic resins, core oils and air-setting oils and as an additive to improve the collapsibility of cores and molds made of clay bonded sand, cement sand and CO_2-sand.

Water-soluble cellulose ethers are obtained from high grade cellulose, preferably dissolving pulp, which is converted to alkali cellulose through mercerizing and treated with suitable etherifying agents. The crude product thus obtained contains salts, etc., and must be carefully washed. After drying and grinding the product is ready and is sold in the form of powder, fibres or granules.

By varying the conditions under which the cellulose ether is produced it is possible to modify important properties, such as the viscosity in water solution. Unlike starch, dextrin and other similar products, water-soluble cellulose ether does not have the tendency to turn sour, mold or ferment under normal conditions. It has no nutritive value and, therefore, destructive insects and animals will not touch it. Contrary to the above-mentioned cereal products, whose properties vary from one harvest to the other, cellulose derivatives can be produced in qualities that remain constant.

Water-soluble cellulose ethers were first produced on a commercial scale in Germany in the 1930's.

* Ornskoldsvik, Sweden, Summarized from an article by the same title appearing in Gjuteriet, Vol 47, August, 1957.

The product manufactured at that time was methyl cellulose, later followed by sodium carboxymethyl cellulose. Other important soluble cellulose ether products now on the market are: ethyl-hydroxyethyl cellulose, methyl-hydroxyethyl cellulose and hydroxyethyl cellulose.

The first time a soluble cellulose ether was used as a binder in foundry work was probably in Germany during the Second World War, when methyl cellulose and sodium carboxymethyl cellulose were used as "unit" binders in core sand due to shortage of raw materials for conventional binders. Cellulose ethers, however, were already at that time used and are still used, as additives in cement sand. After the war, when cereal and oil binders could again be obtained, cellulose ethers no longer held much interest in the foundries. The main reason for this was that cellulose ethers have the following disadvantages when used as foundry binders without suitable strengtheners:

1) A large proportion of water must be added to the sand.

2) The cores have a low dry strength and brittle edges.

3) Cores which are located opposite the ingates in medium and heavy castings are easily destroyed by metal erosion. This is caused partly by the lack of strength of the core and partly because the decomposition of the binder is too rapid.

Before 1951, cellulose ether binders had to be dissolved in water to a thick paste, which was mixed into the sand. The fibrous form in which cellulose ethers then were produced made it impossible to temper the binder directly in the sand. The paste could, furthermore, not be used at once but had to be allowed to swell for a few hours before its use.

Cellulose Ethers in Combination With Synthetic or Natural Resins

Experiments were started in Sweden in 1951 to investigate the possibilities of strengthening soluble cellulose ether, primarily ethyl-hydroxyethyl cellulose, by combining it with other products, such as, synthetic resins in powder form. The aim was to find the most suitable additives, which at the same time were as cheap as possible, and to obtain the desired bonding properties when mixed with cellulose ethers. By utilizing all feasible combinations existing today, it is possible to retain the attractive characteristics of a sand bonded with cellulose ethers, i.e., high green strength and toughness, good plasticity, low gas content and excellent collapsibility, and, at the same time, improve the dry strength control and the collapsibility to suit the actual needs.

Among the many products which have been tried to improve the strength, melamine and urea-formaldehyde resin have proved especially suitable, but other synthetic resins have also given the desired effect as well as rosin and many other substances. By selecting the most appropriate additives and trying out the best proportions it has been possible to arrive at certain standard products which are particularly suitable as "unit" core binders. The quantity normally added to the sand is about 0.8 - 1.5 percent at a moisture content of about 4 - 5 percent.

It was observed that the baked transverse strength of sand bonded with ethyl-hydroxyethyl cellulose alone only reaches a maximum of about 180-200 psi. With a 1 percent addition the figure does not even reach 180 psi. By combining ethyl-hydroxyethyl cellulose with melamine a maximum of about 550 psi is obtained with 1 percent binder consisting of about 20 percent ethyl-hydroxyethyl cellulose and 80 percent melamine.

However, for most purposes it is desirable not only to obtain a high dry strength, but at the same time as high a green strength and toughness as possible. cellulose, with melamine a maximum of about 550 psi Therefore, due consideration must be given to green compressive strength, as well as dry strength when comparing different proportions between ethyl-hydroxyethyl cellulose and melamine. It was found that the ideal combination is 60-80 percent ethyl-hydroxyethyl cellulose and 20-40 percent melamine. This also agrees with industrial experience.

It has been found desirable and suitable to produce core binders based on cellulose ethers and synthetic resins in the form of a powder to facilitate handling both in shipping and use. The powder should be such that it can be stored for an unlimited length of time.

When using these unit binders the desired quantity is mixed dry into the sand. The necessary amount of water is then added and the mix mulled to full strength. The time of mixing is the same as for cereal binders, provided that the cellulose ether is in the form of a fine, quickly dissolved powder in which the synthetic resin has been evenly distributed. The variation of green and dry strengths as a function of moisture when using a commercial quality of such a unit binder is shown in Figures 1 and 2.

It is possible to manufacture combinations of cellulose ethers and synthetic resin suitable for all kinds of metal castings, e.g., aluminum alloys, magnesium alloys, copper alloys, tin, lead, gray iron, malleable iron and steel. Cores made with these binders are baked in ovens in the usual way. Cores produced with cellulose ether combined with synthetic resin may be quickly baked in a high frequency oven with good results since cellulose ether can be dried dielectrically with advantage.

It is possible, by addition of a hardener and proper balancing of cellulose ether and resin, to obtain a

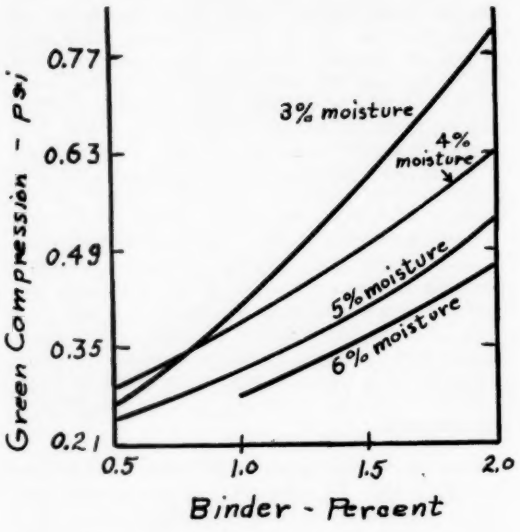

Figure 1—Green compressive strength as a function of amount of binder at different moisture contents. Ethyl-hydroxyethyl cellulose and melamine.

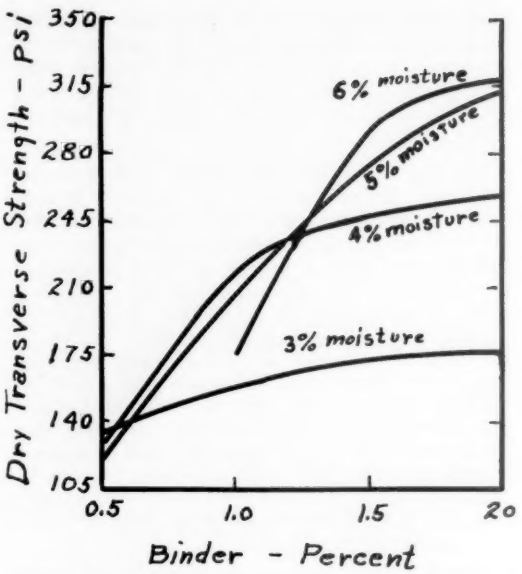

Figure 2—Baked transverse strength as a function of amount of binder at different moisture contents. Ethyl-hydroxyethyl cellulose and melamine. Baking time: 1½ hrs. at 320°F.

sand from which small cores can be made without baking. These cores are air-setting and harden after standing in the air for a few hours.

Gas Content

The gas content of core sand containing a binder based on cellulose ether and synthetic resin is very low. For example, with 1 percent addition of a commercial binder the gas content is only about 13 cu cm/gram of the core sand. A core made with cereal binder and core oil normally has a gas content of 20-30 cu cm/gram.

Collapsibility

It is usually desirable that the core collapses completely after the casting has solidified. This is important with light alloys and thin walled iron castings which are particularly susceptible to cracking due to contraction. The same applies also to all castings where the core is more or less completely surrounded by metal, and in all cases where it is difficult to remove the core sand completely by mechanical means.

Cellulose ethers combined with synthetic resin are in this respect superior to all other known types of binders.

Water-Soluble Cellulose Ethers Replace Cereal Binders in Oil-Sand

Certain cellulose ethers can advantageously replace cereal binders in oil-sand. If, for example, ethyl-hydroxyethyl cellulose is substituted for starch, it is necessary to use a quantity only corresponding to 15-20 percent of the usually used amount of starch to obtain the same green strength and roughly the same dry strength. If ethyl-hydroxyethyl cellulose is used in conjunction with linseed oil, the dry strength is somewhat lower than if starch had been used. This depends partly upon a decrease in the total amount of binder added. It is, therefore, necessary to increase the quantity of linseed oil somewhat. In combination with many other core oils, e.g., esterified tall oil, ethyl-hydroxyethyl cellulose often gives a dry strength which is about the same as when cereal binders are used.

It should be mentioned that products based on cellulose ethers and synthetic resin also can be used in oil-sand, and in such case a good surface hardening can be obtained in the green state. This diminishes the risk of dimensional changes during baking.

Sensitivity to Moisture

Baked oil-sand cores containing starch binders stored in damp places, readily absorb large quantities of moisture. This happens when cores are left for some time in a green sand mold before pouring. The cores under such conditions lose part, and under unfavorable conditions a very large part, of their dry strength besides giving off more gas when surrounded by molten metal.

A simple check on standard transverse cores shows that a linseed oil core with starch, and to still higher degree such a core containing dextrin, is soft and

plastic after 24 hours in a green sand mold. Very little of the original dry strength remains.

A linseed oil core with ethyl-hydroxyethyl cellulose added for green strength only absorbs about half the amount of moisture absorbed by a linseed oil core containing starch when submitted to a similar test. Originally both cores had about the same strength. After 24 hours in a green sand mold a baked transverse test core made in sand with ethyl-hydroxyethyl cellulose and linseed oil is hard and has a transverse strength as least twice as high as the starch/linseed oil core which is plastic.

Comparison Between Different Types of Soluble Cellulose Ethers When Used in Oil-Sand

Dextrin and starch have a tendency to absorb moisture to such a high degree that only 10-20 percent of the original dry strength remains in a standard test core after storing 24 hours in a green sand mold. Cores made with carboxymethyl cellulose are also highly hygroscopic; with methyl cellulose and methyl-hydroxyethyl cellulose they absorb small amounts of moisture but the dry strength is unsatisfactory. Ethyl-hydroxyethyl cellulose and hydroxyethyl cellulose seem to react similarly and both give the best results in this respect.

In view of the fact that 0.4 percent hydroxyethyl cellulose only gives a green strength of 0.5 psi as compared to 0.8 psi for ethyl-hydroxyethyl cellulose, it is obvious that the latter product is to be preferred in this case.

Cellulose ethers generally require a somewhat higher moisture content than starch to give the best green strength, and for this reason they have been difficult to use in core sand with a moisture content below 2 percent. However, new investigations which are not yet finished, show that if through some suitable additive the pH value of the core sand is kept slightly on the alkaline side, pH 7-9, it is possible to use ethyl-hydroxyethyl cellulose in the same way as starch even where the moisture content is low. Such an additive also increases the green strength and toughness.

Thus, according to the desired properties of the cores, cellulose ether together with core oil can either be used in its pure form or be combined with other substances, such as sodium metasilicate which is mixed with cellulose ether in a small quantity so that a suitable pH value is obtained in the sand.

Standard tests show that the green strength in oil-sand with pH controlled ethyl-hydroxyethyl cellulose are not only superior to starch but also to other tested water-soluble cellulose ethers.

Gas Content

Ethyl-hydroxyethyl cellulose and even other cellulose ethers give off smaller quantities of gas than do starch and dextrin. The necessary cellulose ether addition to oil-sand is often considerably smaller than the amount of cereal binder needed to obtain the same green strength. It is for this reason that the gas content must be considerably smaller.

When used as a binder to give green strength, cellulose ether combined with core oil has the following advantages as compared to starch or dextrin:

1) It absorbs considerably less moisture from the surroundings.
2) It has an appreciably lower gas content.
3) Collapsibility after casting is appreciably improved.
4) A smaller quantity of binder is needed.
5) An improved emulsification of the oil can be observed, which results in noticeably smoother surfaces, especially at low binder contents.

The Use of Cellulose Ether to Improve Collapsibility in Other Core and Molding Sands

It is desirable in many cases to increase the collapsibility of core and molding sand after pouring. This problem exists, for instance, in cores made according to the CO_2 process or in clay bonded cores. Good collapsibility is furthermore important in water jacket cores for combustion engines, in making larger thin walled parts in light alloy and cast iron and, as mentioned earlier, in cement sand molding.

It is advisable to use pure cellulose ether in the CO_2 process, e.g., ethyl-hydroxyethyl cellulose, as an additive in the sand in difficult cases up to 1.5 percent. Some of the dry strength is lost but this can be compensated for by the addition of slightly more sodium silicate. In practice it is common to use 4-5 percent sodium silicate together with 0.2-1.5 percent ethyl-hydroxyethyl cellulose calculated on the sand weight.

In clay bonded cores for ingot molds 0.1-0.3 percent pure ethyl-hydroxyethyl cellulose is added. In this way it is easy to remove both mold and core sand together on the shakeout.

Summary

It has been said that the characteristics for a core binder which would approach the ideal are the following:

1) High collapsibility
2) Low retained strength
3) Ease of shakeout
4) Low gas content
5) Good workability in the core box
6) The core binder should require a low moisture content
7) Reduced amount of certain ingredients in the core mix

8) High hot strength for ferrous and some non-ferrous metals

9) Resistance to metal penetration

10) Produce a protective atmosphere

11) Ease of mixing and thoroughness of distribution in the core sand

12) Reduce the number of core sand mixtures in the core shop.

The results which can be obtained today with water-soluble cellulose ethers combined with various additives seems to be able to satisfy these 12 points. Furthermore, by using less binder, working conditions in the foundry are improved, at least as far as trouble-some core fumes are concerned. Water-soluble cellulose ethers have and will have a significant part to play as aid in the foundry technique.

Appendix:

1. Several of the methods described here are protected by patents or pending patent applications in Sweden and abroad.
2. All core sand for tests mentioned in this report is based on pure, washed lake sand, Baskarp No. 6 with an average grain size of 0.27 mm. AFS grain fineness number 55.
3. The different types of water-soluble cellulose ethers tested are available commercially.

ANNUAL REPORT ON STEEL FOUNDERS' SOCIETY'S RESEARCH PROGRAM FOR THE FISCAL YEAR ENDING MARCH 31, 1958

The status of the active research projects and funds of the Society's Research Program, which existed at the end of the fiscal year of the Society, March 31, 1958, are presented in this report.

Only those active projects which have been approved by the Techinacl Research Committee and the Board of Directors are included in this report as research projects.

Projects other than those listed below have been completed and reported to the Society. Projects of numbers greater than 45 have not been adopted.

Continuing Projects

PROJECT NO. 19—*A Study of the Comparative Engineering Characteristics of Steel Castings and Equivalent Structures*

OBJECTIVE—Studies of Design as Related to Methods of Manufacture were formulated by the Product Development Committee and have as their objectives:

(1) To assemble experimental data relative to the responses of certain steel structural elements to loads and stresses imposed in meeting the demands of service. (2) To present the data to the engineering profession in a form which will assist the engineer-designer in securing greater economy of material consistent with good engineering practices.

PRESENT STATUS—The research studies are complete at Case Institute of Technology with all testing finished. A final report has been prepared and submitted to the Research Committee for review and comment. Other interested people have been requested to review the report. The report was very long and academic in character.

The Committee requested that the report be rewritten and that care be given to the manner in which the data are presented so that the values will be significant to the design engineer. During the review of the report Professor Churchill, who directed the work, died, and Professors Wright and Nara took over the activities. A task group of the Committee met with the professors to undertake a reorientation of the data and the report. The report is now to be completely rewritten by the professors and will again be submitted to the Research Committee.

A 30-minute sound movie film on photoelastic studies of joining steel castings and weldments has been prepared during the past year and has been shown at the Fall Meeting and T & O Conference of the Society, and it is now being made available to member companies, customer groups and societies.

PROJECT NO. 30—*Deoxidation and Desulfurization of Cast Steels*

OBJECTIVE—A detailed investigation is to be made of all possible deoxidizing elements and combinations of elements to ascertain their deoxidation and desulfurization efficiency for cast steels.

PRESENT STATUS—Studies were completed during the year and published to the member companies as Research Report No. 39.

PROJECT NO. 37—*Corrosion of Cast Steels*

OBJECTIVE—Research on the corrosion resistance of cast steels is undertaken so as to increase the knowledge on this subject and to ascertain the extent of variations between the corrosion of carbon and alloy cast steels and their relation to wrought steel of similar composition.

PRESENT STATUS—Seven steel foundries were requested to produce nine carbon and low-alloy cast steels in plate form, both in machined and unmachined condition for inclusion in the test racks at Kure Beach and East Chicago. The steels have been in the ASTM test racks 4 years. Progress reports have been prepared on the test results for both the one and the three year periods. A progress report

on the corrosion resistance was given in the May, 1957, issue of the Journal of Steel Castings Research. The next test period is 4 years, and the specimens will come off the racks in October, 1960.

PROJECT NO. 41—*The Effect of Section Design on Hot Tear Formation*

OBJECTIVE—An investigation of the variations in the design of sections and their effect on hot tears in steel castings. In this regard attention is to be given to the character of temperature gradients, volume and surface area ratios of the sections, and the character of the restraint involved.

PRESENT STATUS — Massachusetts Institute of Technology has completed two years of research on design studies and their importance in the formation of hot tears. The results of these studies have been published to the members in Research Report No. 38.

The studies are continuing with consideration being given to cylindrical shapes and to the formation of bore cracks and their possible elimination and to the extension of studies on box-shaped sections.

It is shown in progress reports that segregation at hot spots or surface points is most conducive to the formation of hot tears. Therefore, the fundamentals of chilling to prevent segregation are important. Studies on the placing of chills to prevent bore cracking showed that in many cases chills are placed incorrectly and that the normally used procedures merely accentuate the segregation rather than prevent it. A box section design has been prepared, and studies similar to those on joined cylindrical castings are going forward.

PROJECT NO. 42—Part I—*An Investigation of the Factors Influencing Toughness on the Heat Treatment of Cast Steel*

OBJECTIVE—This investigation has been formulated by the Ordnance Department of the U. S. Army for the purpose of exploring variations in the methods and procedures of the heat treatment of low-alloy steels to ascertain means of further improving the toughness of these steels and, if possible, reducing the heat treating times.

PRESENT STATUS—Cast steel test bars in 1, 3 and 6-inch section sizes were obtained from 5 steel foundries, and extensive heat treating studies were undertaken to ascertain the effect of time and temperature on the impact and tensile properties of homogenization, quenching, tempering, double tempering, interrupted quenching and aging treatments.

Difficulty was encountered in the reproducibility of results causing considerable rechecking and investigation of equipment and position of test samples out of coupons. This phase of the studies was completed by March 1957.

Phase II studies, which covered tempering treatments only, included varying the time and temperature of tempering to produce a constant hardness value for impact and tension tests. Four cast steels for Phase II have been procured and preliminary testing to check on the normal variations in testing has been completed.

Full scale testing of the 4 cast steels is complete, and a very extensive report in thirteen sections, with numerous tables and figures, has been prepared and reviewed by the Committee. The report has now been submitted to the printer and will be made available to the member companies in the near future. The studies of this research show a new concept in the heat treating of steel castings, namely, the short time heat treating without prior homogenizing heat treatments. It is hoped that these studies will permit the industry to discard the hour-per-inch rule.

PROJECT NO. 42—Part II—*The Influence of Deoxidation on the Toughness of Cast Steel With Short Time Heat Treatment*

OBJECTIVE—The impact properties of cast steel can be affected by the melting and deoxidation practice of the producing foundry. It was, therefore, decided to investigate the influence which the Society's new deoxidizer has on the impact properties.

PRESENT STATUS—A plan of study for various low-alloy cast steels was devised to include all phases of steel making methods. Steels of the same type having normal deoxidation and the Society's deoxidizer were produced. Fourteen cast steels from member companies were scheduled. All but four have been made as of March 31st. The heat treatment, machining of test specimens and impact and tensile testing are being carried on by a member foundry.

PROJECT NO. 43—*Inorganic Bonding of Molding Materials*

OBJECTIVE—The research investigations are designed to study the properties and behaviors of potential inorganic bonds, other than clay, and to develop materials and processes suitable for the bonding of molding materials for the production of steel castings.

PRESENT STATUS—A systematic investigation is being made of the use of the sodium silicate—CO_2 process of bonding molding sands and cores. Studies on setting time, green strength, thermal shock resistance, properties at high temperatures, dimensions and size stability during curing, gas evolution, reactivity with molten steel, mold erosion and shakeout difficulties have gone forward at Horizons, Inc. Control of all variables has been accomplished. Studies on other systems of inorganic bonds are going forward.

Field tests at 7 steel foundries have been made which assisted in the development of improved properties and understanding of molding methods. A final report on the studies has been made available to the Committee for review and study. Studies are being made on other systems of inorganic bonds

covering the phosphates, i.e., aluminum phosphate and Alkophos.

PROJECT NO. 44—*An Investigation of Close Packing of Sand and Development of Effective Clay Bonds*

OBJECTIVE—It is planned by the research to improve the surface of steel castings through the elimination of included mold materials by more thoroughly understanding the basic relationship of sand grain distribution and the effectiveness of clay bonds.

PRESENT STATUS—The studies are being carried forward at Massachusetts Institute of Technology. Studies have been made on bentonite to ascertain the importance of the sodium oxide-calcium oxide ratio. Other variables under study include: (1) concentration of electrolytes in the pure liquid of the clays, (2) amount of water-electrolyte solution to be used, (3) yield point, deformation and shear strength of clays, (4) liquid and plastic limits, (5) compression, tensile strength and deformation of sand-clay mixtures, and (6) pH and rate of sedimentation of clays in different media, and (7) the effect of grain distribution on packing.

Considerable attention has been given to the study of bentonite and what constitutes acceptable bentonite for steel foundry use. The Liquid Limit Test has been devised for test purposes and a standard procedure has been developed. This information has been turned over to the Specifications Committee to use in establishing a raw material specification.

Research Report No. 40, "The Significance of Liquid Limit in Evaluating Steel Foundry Bentonites", was issued in December. This report considers the structure of bentonites and the problem of plasticity of clay-water systems and measuring methods. The report presents all of the information available at present on the significance of the Liquid Limit Test in evaluating steel foundry bentonites.

PROJECT NO. 45—*Organic Bonding of Steel Foundry Molding Sands*

OBJECTIVE—It is planned to study the properties and behaviors of all potential organic bonds and to ascertain their effectiveness when bonded with molding sands in the production of steel castings.

PRESENT STATUS—Studies have been undertaken between Monsanto Chemical Company, MIT and SFSA. Organic materials which have any possibility as a bonding material are being studied. These materials are first studied at Monsanto and if they show promise they are forwarded to MIT for production as molds, and poured with steel. Resulting castings are studied as to their quality characteristics. Such information leads to further modifications by Monsanto and additional testing.

The studies to date indicate that there is very little possibility of using resins outside of the phenol formaldehyde field. Cold coated and hot coated resins have been investigated, but all indicate imperfect surfaces for carbon and low-alloy steels. It seems advisable for the coming year to include molding materials other than silica sand in the studies.

RESEARCH FINANCIAL REPORT
FOR THE FISCAL YEAR ENDING MARCH 31, 1958

RESEARCH PROJECT DETAILS
March 31, 1958

Project No.	Appropriations	Expenditures	Unexpended
19	$ 42,710.00	$ 37,744.74	$ 4,965.26
37	5,000.00	447.20	4,552.80
38	32,150.68	31,613.95	536.73
41	65,408.91	59,925.04	5,483.87
42A*	59,934.02	59,934.02	—0—
42B*	15,500.00	8,694.01	6,805.99
Research Report Summary	1,750.00	—0—	1,750.00
43	116,000.00	83,294.59	32,705.41
44	63,500.00	52,188.03	11,311.97
45	20,350.00	7,842.91	12,507.09
	$422,303.61	$341,684.49	$80,619.12

*Appropriated as billings are made to U. S. Ordnance.

STATEMENT OF RESEARCH RESERVES
April 1957 - March 1958

Balance—March 31, 1957		$113,423.02
Increments from Members' Dues	$125,000.00	
Received from U. S. Ordnance	13,552.35	
Expenditures Charged to Reserves	−94,150.15	
Net Change in Reserves		44,402.70
Balance—March 31, 1958		$157,825.72
Research Reserve for New Projects		$ 77,206.60
Research Reserve Appropriated for Approved Projects		80,619.12
Total per Balance Sheet		$157,825.72